

**Organometallic chemical vapor deposition of films utilizing organic heterocyclic compounds**

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**Abstract**

There is provided a method of producing inorganic thin films by metal inorganic chemical vapor deposition. The method comprises forming a vapor stream comprising a vapor mixture of an organometallic compound and a heterocyclic organic compound incorporating a group V or group VI element, and thermally decomposing the mixture on a heated substrate to form an inorganic layer. The heterocyclic compound may be an aliphatic or aromatic ring compound. The mixture may include vapors appropriate for deposition of ternary or higher order compounds, and/or for introducing dopants.

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## Description

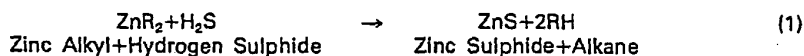
This invention relates to organometallic chemical vapour deposition of films of inorganic materials. The method is particularly, although not exclusively, relevant to thin film production.

It is known to employ organometallic vapour deposition for inorganic film production. In particular UK Pat. No. 1,600,286 describes a method of III—V compound thin film production wherein a mixture of a group III metal alkyl and a group V element hydride in a hydrogen stream are thermally decomposed to form a III—V compound film on a substrate. More generally, the method of Metal Organic Chemical Vapour Deposition (hereinafter called MOCVD) has been employed to produce thin films of various II—V and II—VI compounds and their alloys. The starting reagents normally employed in this method are the metal alkyls of the elements of groups II and III and the hydrides or alkyls of the elements of groups V and VI. Examples of such reagents are shown in Table I below, where R represents an alkyl group (methyl, ethyl, propyl, butyl, etc. along the homologous series).

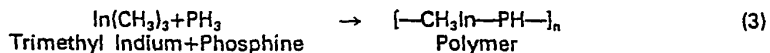
TABLE I  
Examples of known MOCVD reagents

Group II alkyls	Group III alkyls
ZnR <sub>2</sub> CdR <sub>2</sub> HgR <sub>2</sub> BeR <sub>2</sub> MgR <sub>2</sub>	GaR <sub>3</sub> AlR <sub>3</sub> InR <sub>3</sub> BR <sub>3</sub>
Hydrides of group V	Hydrides of group VI
AsH <sub>3</sub> PH <sub>3</sub> SbH <sub>3</sub> NH <sub>3</sub>	H <sub>2</sub> S H <sub>2</sub> Se H <sub>2</sub> O
Alkyls of group V	Alkyls of group VI
AsR <sub>3</sub> PR <sub>3</sub> SbR <sub>3</sub> NR <sub>3</sub>	SR <sub>2</sub> SeR <sub>2</sub> TeR <sub>2</sub> OR <sub>2</sub>

Equations representing typical reactions employed in MOCVD are:



Although MOCVD has been used successfully to prepare various of II—VI and III—V compounds and alloys, preparation problems may arise. In some cases, "parasitic" or "premature" reactions occur at room temperature when the reagents are mixed. These give rise to undesirable premature reaction products, and cause non-uniformities in thicknesses and electrical and optical properties in the deposited films. Such "parasitic" reactions adversely affecting the deposition processes include:



The polymeric material indicated in Reaction (3) is solid; its formation depletes the gas phase of reagents. Reagent depletion affects the processes occurring in the film deposition zone of the reactor.

The phosphorus atom of the hydride possesses a lone pair of electrons, the pair being readily available for bond formation (Lewis Base). Moreover, the indium of the alkyl is strongly electron accepting (Lewis Acid). As an initial consequence of these acidic and basic properties, a co-ordination bond forms between the indium and phosphorus. Subsequently, methane is eliminated to form the polymer in reaction (3) above.

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A further prior art reaction used to prepare zinc sulphide thin films is as follows:



Reaction (4) occurs to a degree at room temperature, and consequently the gas phase becomes depleted prior to the film deposition zone being reached. It is an object of the present invention to provide an alternative method of MOCVD production of thin films.

The present invention provides an MOCVD method of inorganic film production including the steps of:  
(1) forming a vapour stream consisting at least partly of a mixture of the vapours of an organometallic compound and an organic compound incorporating a group V or group VI element; and  
(2) passing the vapour stream over a heated substrate for reaction and decomposition of the organometallic and organic compounds to deposit an inorganic thin film having metal and group V or group VI element constituents.

Characterised in that the organic compound is a heterocyclic compound having the group V or group VI element as a ring member, other ring members being carbon and the ring having no side bonds to elements other than hydrogen.

It has been found that the incorporation of the group V or group VI element in a heterocyclic compound inhibits undesirable reactions upstream of the heated substrate when employed in MOCVD film production. This is advantageous as compared to the use of prior art group V or group VI hydrides or alkyls on MOCVD, since it reduces the scope for reagent depletion and consequent film non-uniformity arising from premature vapour reaction. The method of the invention is particularly appropriate for use in organic thin film production, where film non-uniformity is highly undesirable.

The method of the invention may be employed in the production of II—VI, III—VI or III—V binary film compounds, or for the production of related ternary or quaternary materials where appropriate volatile organometallic and heterocyclic compounds exist. The invention may also be used for producing group III—V material doped with group VI elements, or group II—VI materials doped with group V elements. In each case the appropriate vapour stream mixture is formed.

The group V or VI element may be incorporated in aliphatic heterocyclic ring compounds, such as cyclic arsines, cyclic stibines, cyclic amines, cyclic ethers, cyclic thioethers, cyclic selenoethers and cyclic telluroethers. Alternatively, the group V or VI elements may be incorporated in aromatic heterocyclic ring compounds, such as arsoles, phospholes, stiboles, pyrroles, furans, thiophenes, selenophenes or tellurophenes.

ZnS and ZnO films may be produced in accordance with the invention for the production of DC or AC electroluminescent panels.

The invention will now be described by way of example only with reference to the accompanying examples and drawings in which:

Figure 1 illustrates MOCVD equipment; and

Figures 2 and 3 are schematic cross-sectional views of electroluminescent devices including layers made in accordance with the invention.

Referring to Figure 1, a mixed zinc alkyl/hydrogen sulphide vapour stream 10 enters a reaction vessel 11 at a neck 12 for the purposes of a prior art MOCVD technique of inorganic thin film production. The vapour stream 10 is intended to decompose to a zinc sulphide film (with the release of an alkane) on a heated substrate 13. The substrate 13 is supported on a susceptor block 14 rf heated by a coil 15 and rf supply (not shown). Due to undesirable or premature reactions the stream 10 may decompose on the walls 16 of the vessel 11. This decomposition may produce deposits 17 upstream and downstream of the susceptor block 14. Such deposition occurs particularly in the reaction of hydrogen sulphide and dimethyl zinc, which react to produce zinc sulphide and methane as set out in Reaction (4) above. Premature reaction leads to deposits upstream of the susceptor block 14, which receives a seriously depleted vapour stream resulting in non-uniform film growth. Downstream reaction, being after deposition, does not influence film uniformity.

Table II gives reaction details of Examples (1) to (7) of the production of zinc sulphide, zinc oxide and zinc selenide films in accordance with the invention, i.e. employing heterocyclic compounds of sulphur and oxygen in place of the prior art hydrides or alkyls. Temperatures in parentheses indicate the temperatures at which the relevant liquids are maintained, which controls the vapour pressure of the corresponding constituent in the vapour mixture stream.

Whereas Examples (1) to (7) are binary compounds, ternary or higher order compounds may be produced by forming appropriate mixtures of vapour streams. Similarly, films doped with impurities may be formed by including in the vapour stream 10 a proportion of the vapour of a suitable volatile compound containing the impurity. In particular, manganese-doped ZnS may be produced by adding methylcyclopentadienyltricarbonyl manganese to the vapour stream 10. Moreover, multilayer structures may be deposited by employing a succession of different vapour streams of appropriate compositions.

Referring now to Figures 2 and 3, these show respectively schematic cross-sectional views of conventional DC and AC electroluminescent devices which may be produced with the aid of the invention.

In Figure 2, a glass substrate 20 bears a ZnO transparent electrically conducting thin film 21 laid down in accordance with Example (3). An Mn-doped ZnS electroluminescent film 22 is laid on the ZnO layer 21 in accordance with Example (1) or (2). A current control layer 23 and a metallisation layer 24 produced by conventional techniques complete the electroluminescent device. In Figure 3, an Mn-doped ZnS electroluminescent film 30 is arranged between upper and lower insulating dielectric films 31 and 32 upon a ZnO transparent conducting film 33. The multilayers 30 to 33 are mounted on a substrate 34 and have an uppermost metallisation layer 35. The ZnS and ZnO layers may be produced in accordance with the Examples, and the dielectric layers by conventional techniques.

In reactions in accordance with the Examples, it has been found that there has been no observable unwanted film deposition upstream of the substrate 13. Furthermore, the films of ZnS and ZnO produced have shown no visible degree of wedge non-uniformity. ZnS films produced by prior art techniques may exhibit visible wedge interference fringes, indicating greater thickness in the upstream region as compared to that downstream, a consequence of reactant depletion in the vapour stream. Accordingly, films produced in accordance with the invention exhibit improved uniformity as compared to the prior art.

The invention reduces the scope for vapour depletion by inhibiting undesirable or "parasitic" reactions. To achieve this, the group V or VI elements are incorporated in heterocyclic compounds which may be either aliphatic or aromatic. Examples of aliphatic heterocyclic ring systems are cyclic phosphines, cyclic arsines, cyclic stibines, cyclic amines, cyclic ethers, cyclic thioethers, cyclic selenoethers and cyclic telluroethers. Examples of aromatic heterocyclic ring systems are arsoles, phospholes, stiboles, pyrroles, furans, thiophenes, selenophenes and tellurophenes.

In addition to its use to prepare ZnS and ZnO, the invention is applicable to the production of other II—VI compounds and alloys thereof.

The II—VI binary compounds are:

ZnO	CdO	HgO
ZnS	CdS	HgS
ZnSe	CdSe	HgSe
ZnTe	CdTe	HgTe

The invention is also applicable to the preparation of the III—V compounds and their alloys, the binary III—V compounds being:

BN	AlN	GaN	InN
BP	AlP	GaP	InP
BAAs	AlAs	GaAs	InAs
BSb	AlSb	GaSb	InSb

The invention is further applicable to other binary and higher order oxides and compounds, such as  $Al_2O_3$ ,  $Ga_2O_3$ ,  $SiO_2$ ,  $Zn_2SiO_4$ , etc. and derivatives thereof where suitable volatile metal organic and related compounds exist.

Inorganic films produced in accordance with the invention have a wide range of possible uses, such as the following (examples are given in parenthesis):

1. Luminescent panels (ZnS)
2. Transparent conductors (ZnO)
3. Surface acoustic wave devices (ZnO)
4. Microwave devices (InP)
5. Light emitting diodes (GaInAsP)
6. Solid state lasers (GaInAsP)
7. Hard coatings (AlN)
8. Solar cells (CdS)
9. Phosphors (ZnS,  $Zn_2SiO_4$ )
10. Antireflection coatings (ZnS)

TABLE II  
Growth conditions

Example 1				
Growth of ZnS				
Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn (DMZ)			
	Thiophene C <sub>4</sub> H <sub>4</sub> S			
Carrier gas	H <sub>2</sub>			
Substrate temperature	500°C			
Flow rates	DMZ	5 cc/min	(-10°C)	
	Thiophene (large excess)	50 cc/min	(20°C)	

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TABLE II (contd.)  
Growth conditions

5	Example 2			
	Growth of ZnS			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Tetrahydrothiophene Tetramethylenesulphide	C <sub>4</sub> H <sub>8</sub> S	
	Carrier gas	H <sub>2</sub>		
10	Substrate temperature	500—650°C		
	Flow rates	DMZ	5 cc/min	(-10°C)
		C <sub>4</sub> H <sub>8</sub> S	200 cc/min	(20°C)
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15	Example 3			
	Growth of ZnO			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Furan C <sub>4</sub> H <sub>4</sub> O		
	Carrier gas	H <sub>2</sub> (Helium carrier gas may also be employed, but under different conditions)		
20	Temperature	400°C		
	Flow rates	DMZ	2.5 cc/min	(-10°C)
		Furan (large excess)	80 cc/min	(20°C)
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25	Example 4			
	ZnSe			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Selenophene C <sub>4</sub> H <sub>4</sub> Se		
	Carrier gas	H <sub>2</sub>		
30	Substrate temperature	450—625°C		
	Flow rates	DMZ	5 cc/min	(-10°C)
		Selenophene	100 cc/min	(20°C)
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35	Example 5			
	ZnO			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Ethylene oxide	C <sub>2</sub> H <sub>4</sub> O	
	Carrier gas	H <sub>2</sub>		
40	Substrate temperature	400°C		
	Flow rates	DMZ	3 cc/min	(-10°C)
		Ethylene oxide	200 cc/min	(20°C)
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45	Example 6			
	ZnO			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Tetrahydropyran	C <sub>5</sub> H <sub>10</sub> O	
	Carrier gas	H <sub>2</sub>		
50	Substrate temperature	300—450°C		
	Flow rates	DMZ	3 cc/min	(-10°C)
		Tetrahydropyran	200 cc/min	(20°C)
<hr/>				
55	Example 7			
	ZnO			
	Reactants	(CH <sub>3</sub> ) <sub>2</sub> Zn Tetrahydrofuran	C <sub>4</sub> H <sub>8</sub> O	
	Carrier gas	H <sub>2</sub>		
60	Substrate temperature	350—400°C		
	Flow rates	DMZ	5 cc/min	(-10°C)
		Tetrahydrofuran	200 cc/min	(20°C)

## Claims

1. A method of inorganic thin film production including the steps of:—

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- forming a vapour stream (10) consisting at least partly of a mixture of the vapours of an organometallic compound and an organic compound incorporating a group V or group VI element, and passing the vapour stream (10) over a heated substrate (11) for reaction and decomposition or the organometallic and organic compounds to deposit an inorganic thin film having metal and group V or group VI element constituents,
- characterised in that the organic compound is a heterocyclic compound having the group V or group VI element as a ring member, other ring members being carbon and the ring having no side bonds to elements other than hydrogen.
2. A method according to Claim 1 characterised in that the organometallic compound incorporates a group II or group III element.
3. A method according to Claim 2 characterised in that the vapour stream (10) consists at least partly of a mixture of three or more vapours for deposition of ternary or higher order compounds.
4. A method according to Claim 2 or 3 characterised in that the vapour mixture includes a vapour appropriate to provide a film dopant when co-deposited with other film constituents.
5. A method according to any preceding claim characterised in that the heterocyclic organic compound is an aliphatic ring compound such as a cyclic amine, cyclic arsine, cyclic stibine, cyclic ether, cyclic thioether, cyclic selenoether or a cyclic telluroether.
6. A method according to any one of Claims 1 to 4 characterised in that the heterocyclic organic compound is an aromatic ring compound such as an arsole, phosphole, stibole, pyrrole, furan, thiophene, selenophene, or a tellurophene.

### Patentansprüche

1. Verfahren zur Herstellung anorganischer dünner Filme mit den Verfahrensschritten
- a) Erzeugung einer Dampfströmung (10), die zumindestens teilweise aus einem Gemisch des Dampfes einer organometallischen Verbindung und des Dampfes einer, ein der Gruppe V oder der Gruppe VI angehörendes Element enthaltenden organischen Verbindung besteht, und
- b) Führung der Dampfströmung (10) über ein erhitztes Substrat (11) zwecks Reaktion und Dekomposition der organometallischen und der organischen Verbindung und Niederschlag eines anorganischen dünnen Filmes, der Bestandteile von der Gruppe V oder der Gruppe VI angehörenden Elementen enthält,
- dadurch gekennzeichnet, daß die organische Verbindung eine heterozyklische Verbindung ist, die das der Gruppe V oder VI angehörige Element als Ringbestandteile enthält, während Kohlenstoff die anderen Ringbestandteile bildet und der Ring keine Seitenbindungen zu anderen Elementen außer zu Wasserstoff aufweist.
2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß die organometallische Verbindung ein der Gruppe II oder der Gruppe III zugehöriges Element enthält.
3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die Dampfströmung (10) zumindestens teilweise ein Gemisch von drei oder mehr Dämpfen zwecks Niederschlagung von ternären Verbindungen oder Verbindungen höherer Ordnung enthält.
4. Verfahren nach Anspruch 2 oder 3, dadurch gekennzeichnet, daß das Dampfgemisch einen Dampf enthält, der, wenn er gleichzeitig mit anderen Filmbestandteilen niedergeschlagen wird, ein Filmdopant ergibt.
5. Verfahren nach einem der vorstehenden Ansprüche, dadurch gekennzeichnet, daß die heterozyklische organische Verbindung eine aliphatische Ringverbindung wie beispielsweise Zykloamin, Zykloarsen, Zyklostibin, Zykloäther, Zyklothioäther, Zykloselenäther oder Zyklotelluräther ist.
6. Verfahren nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß die heterozyklische organische Verbindung eine aromatische Verbindung wie beispielsweise Arsol, Phosphol, Stibol, Pyrrol, Furan, Thiophen, Selenophen oder Tellurophen ist.

### Revendications

1. Un procédé pour produire une pellicule minérale mince comprenant les stades de: formation d'un courant de vapeurs (10) constitué au moins partiellement d'un mélange des vapeurs d'un composé organométallique et d'un composé organique comprenant un élément du groupe V ou du groupe VI, et
- passage du courant de vapeurs (10) sur un substrat (11) chauffé pour la réaction et la décomposition des composés organométallique et organique pour déposer une pellicule minérale mince ayant un métal et un élément du groupe V ou du groupe VI,
- caractérisé en ce que le composé organique est un composé hétérocyclique ayant l'élément du groupe V ou du groupe VI comme constituant nucléaire, les autres constituants nucléaires étant des carbones et le cycle n'ayant pas de liaison latérale à des éléments autres que l'hydrogène.
2. Un procédé selon la revendication 1, caractérisé en ce que le composé organométallique comprend un élément du groupe II ou du groupe III.
3. Un procédé selon la revendication 2, caractérisé en ce que le courant de vapeurs (10) est constitué au

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moins partiellement d'un mélange de trois ou de plus de trois vapeurs pour déposer des composés ternaires ou d'ordre supérieur.

4. Un procédé selon la revendication 2 ou 3, caractérisé en ce que le mélange de vapeurs comprend une vapeur appropriée à fournir un dopant de la pellicule lorsqu'elle est codéposée avec les autres  
5 constituants de la pellicule.

5. Un procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que le composé organique hétérocyclique est un composé cyclique aliphatique tel qu'une amine cyclique, une arsine cyclique, une stibine cyclique, un éther cyclique, un thioéther cyclique, un sélénioéther cyclique ou un telluroéther cyclique.

10 6. Un procédé selon l'une quelconque des revendications 1 à 4, caractérisé en ce que le composé organique hétérocyclique est un composé cyclique aromatique tel qu'un arsole, un phosphole, un stibole, un pyrrole, un furanne, un thiophène, un sélénophène ou un tellurophène.

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